Name ____ AP Chemistry

Solubility Product POGIL

Model #1: The Dissolution of $Mg(OH)_2$ in Water

When solid $Mg(OH)_2$ dissolves in water the chemical reaction is

$$Mg(OH)_2\ (s) \leftrightarrow Mg^{2+}\ (aq) + 2\ OH^-\ (aq)$$

The results after equilibrium has been established of adding $Mg(OH)_2$ to 10.0 L H_2O

Total Amount of $Mg(OH)_2$ added		**Equilibrium Concentrations**		**Mass of $Mg(OH)_2$ not dissolved (g)**
g	*moles*	*$[Mg^{2+}]$ (M)*	*$[OH^-]$ (M)*	
0.00963	1.65×10^{-4}	1.65×10^{-5}	3.33×10^{-5}	0.00000
0.04815	8.26×10^{-4}	8.26×10^{-5}	1.65×10^{-4}	0.00000
0.09590	1.64×10^{-3}	1.64×10^{-4}	3.29×10^{-4}	0.00000
0.09630	1.65×10^{-3}	1.65×10^{-4}	3.30×10^{-4}	0.00000
0.09700	1.66×10^{-3}	1.65×10^{-4}	3.30×10^{-4}	0.00070
0.10000	1.71×10^{-3}	1.65×10^{-4}	3.30×10^{-4}	0.00370
0.15000	2.57×10^{-3}	1.65×10^{-4}	3.30×10^{-4}	0.05370
0.20000	3.43×10^{-3}	1.65×10^{-4}	3.30×10^{-4}	0.10370

1) When 8.26×10^{-4} moles of $Mg(OH)_2$ are added, why is $[Mg^{2+}] = 8.26 \times 10^{-5}$ M and $[OH^-] = 1.65 \times 10^{-4}$ M?

2) According to the table, what is the maximum number of moles of $Mg(OH)_2$ that can be dissolved in *10.0 L* H_2O?

3) Based on your answer for question 2, what is the maximum number of moles of $Mg(OH)_2$ that can be dissolved in *1.00 L* H_2O? What is the maximum number of grams of $Mg(OH)_2$ that can be dissolved in *1.00 L* H_2O?

4) Using the maximum number of moles from question 3, what is the maximum value for the expression $[Mg^{2+}][OH^-]^2$?

Model #2: Solubility Product Expression

Once equilibrium is established between a solid and the associated aqueous species, the solution is said to be saturated. For $Mg(OH)_2$, we say the solubility of magnesium hydroxide is 9.63×10^{-3} g/L or that the solubility of magnesium hydroxide is 1.65×10^{-3} M.

By convention, if a saturated solution of an ionic compound is greater than about 0.1 M, we say that the compound is soluble. If the saturated solution is less than about 0.001 M, the compound is said to be insoluble. Intermediate cases are said to be moderately or slightly soluble. Experimental evidence has shown that essentially all compounds, containing the nitrate ion, NO^{3-}, and also all those containing the sodium ion, Na^+, are soluble in water. Silver chloride is so insoluble in water that a saturated solution contains only 0.002 g of AgCl per liter of water. Hence if a mere 1.000 g AgCl were added to a liter of water the following equilibrium would be present between the 0.998 g of undissolved AgCl and the 0.002 g of ions in solution:

$$AgCl\ (s) \leftrightarrow Ag^+\ (aq) + Cl^-\ (aq)$$

5) Write the equilibrium expression for AgCl reaction above.

6) Since this equilibrium constant is proportional to the solubility of the salt, it is called the solubility product equilibrium constant for the reaction, or K_{sp}. The K_{sp} expression for a salt is the product of the concentrations of the ions, with each concentration raised to a power equal to the coefficient of that ion in the balanced equation for the solubility equilibrium. Write the K_{sp} expression for the following ionic compounds.
   (a) Calcium fluoride
   (b) Magnesium phosphate
   (c) Iron (III) hydroxide
   (d) Mercury (I) iodide

Model #3: Relationship between K_{sp} and the Solubility of a Salt

K_{sp} is called the solubility product because it is literally the product of the solubilities of the ions in moles per liter. The solubility product of a salt can therefore be calculated from its solubility, or vice versa. Like all equilibrium constants, a given K_{sp} value depends only on the temperature, not on the individual ion concentrations.

Photographic films are based on the sensitivity of silver bromide to light. When light hits a crystal of AgBr, a small fraction of the Ag+ ions are reduced to silver metal. The rest of the Ag+ ions in these crystals are reduced to silver metal when the film is developed. AgBr crystals that do not absorb light are then removed from the film to "fix" the image. Can the silver bromide be removed by simply washing the film in water? Let's see by calculating the solubility of AgBr in water in grams per liter.

7) Let's calculate the solubility of AgBr in water in grams per liter, to see whether AgBr can be removed by simply washing the film. The K_{sp} for silver bromide is 5.0 x 10^{-13} at 25°C.
   (a) Start by writing the balanced chemical equation for the equilibrium and the corresponding K_{sp} expression:

   AgBr (s) ↔ _____ (aq) + ______ (aq)

   K_{sp} = 5.0 x 10^{-13} =

   (b) Calculate the [Ag^+] and [Br^-] in moles per liter.

   (c) Calculate the solubility of silver bromide in grams AgBr per liter.

   (d) Based on your response to part c, above, is it practical to try to wash the unexposed AgBr off photographic film with water? Explain.

8) Calcium fluoride has been studied as possible source of fluoride ion for use in toothpaste.
   (a) As the first step toward evaluating its use as a fluoridating agent, write the balanced chemical equation that describes the relationship between the solubility of solid CaF_2 and the equilibrium concentrations of the Ca^{2+} and F^- ions in a saturated aqueous solution.

   (b) Calculate the solubility of calcium fluoride in grams per liter. Comment on the potential of CaF_2 to act as a fluoridating agent. (CaF_2: K_{sp} = 4.0 x 10^{-11})

Model #4: Using K_{sp} as a Measure of the Solubility of a Salt

The K_a for an acid is proportional to the strength of the acid. Hence, we can immediately conclude that formic acid (HCOOH, $K_a = 1.8 \times 10^{-4}$) is a stronger acid than acetic acid (CH_3COOH, $K_a = 1.8 \times 10^{-5}$). The same can be said about values of K_b: Methylamine (CH_3NH_2, $K_b = 4.8 \times 10^{-4}$) is a stronger base than ammonia (NH_3, $K_b = 1.8 \times 10^{-5}$). Unfortunately, there is no simple way to predict the relative solubilities of salts from their K_{sp}'s if the salts produce different numbers of positive and negative ions when they dissolve in water.

9) Which salt, $CaCO_3$ ($K_{sp} = 2.8 \times 10^{-9}$) or Ag_2CO_3 ($Ksp = 8.1 \times 10^{-12}$) is more soluble in water in units of moles per liter? (Hint: This question requires a calculation—calculate the molar solubility of each salt!)

10) A list of K_{sp} values like that on page p. 718 in your textbook can be used to compare the solubility of silver chloride, AgCl, directly with that of silver bromide, AgBr, but not with that of silver chromate, Ag_2CrO_4. Explain.

11) Compare the K_{sp} values on page p.718 in your textbook to determine which of the following is more soluble in water?
(a) Strontium sulfate or barium chromate

(b) Calcium carbonate or copper (II) carbonate

(c) Barium iodate or silver chromate

Model #5: Role of the Ion Product (Q_{sp}) Predicting the Formation of a Precipitate

When a solution is not saturated the product of the concentrations of the ions dissolved in solution is less than the value for the K_{sp}. In this case, the product of the concentration of the ions is called the ion product, Q_{sp}. One of the most useful applications of K_{sp} and Q_{sp} is to predict whether a precipitate will form when two solutions are mixed.

12) If the ions of a slightly soluble substance are brought together, three types of situations are possible. Match the statement below that best corresponds with the three situations involving Q_{sp} and K_{sp}.
(a) No precipitate forms: The solution is unsaturated and the system not at equilibrium. To establish equilibrium Q_{sp} must increase to the value of K_{sp}, which means the concentrations of ions in solution are insufficient to produce a saturated solution.
(b) Precipitate is present: The solution is saturated and an equilibrium exists between dissolved and undissolved solute.
(c) More precipitate will form: The system is not at equilibrium and more precipitate must form to attain equilibrium. To establish equilibrium, the value of Q_{sp} must decrease to the value of K_{sp}, which means the concentrations of ions must be decreased. To do so ions combine to give solid.

(i) $Q_{sp} = K_{sp}$: a, b or c?
(ii) $Q_{sp} < K_{sp}$: a, b or c?
(iii) $Q_{sp} > K_{sp}$: a, b or c?

13) Does any solid lead (II) chloride, $PbCl_2$, form when 3.5 mg NaCl is dissolved in 0.250 L of 0.12 M $Pb(NO_3)_2$?

Questions

1) Write the equilibrium equation and the K_{sp} expression for a and b and write the equilibrium equation and chemical formula for the K_{sp} expression in c and d:
   (a) MnS_2
   (b) $Zn_2P_2O_7$
   (c) $[Mn^{4+}][O^{2-}]^2$
   (d) $[Co^{3+}][OH^-]^3$
2) (a) If the molar solubility of CaF_2 at 35°C is 1.24×10^{-3} mol/L, what is the K_{sp} at this temperature?
   (b) It is found that 1.1×10^{-2} g of SrF_2 dissolves per 100 mL of aqueous solution. Calculate the solubility product for SrF_2.
   (c) The K_{sp} of $Ba(IO_3)_2$ is 6.0×10^{-10}. What is the molar solubility of $Ba(IO_3)_2$?
3) Calculate the solubility (in grams per liter) of magnesium hydroxide in the following: (a) pure water, (b) 0.041 M $Ba(OH)_2$, and (c) 0.0050 M $MgCl_2$.